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Exploring Magneto-Optical Properties of Novel Structures

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Exploring Magneto-Optical Properties of Novel Structures

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Abstract

An optical isolator can be constructed with two polarizers and a device that can rotate the polarization of light. The goal of my summer project was to create such a device by synthesizing a material that could rotate the polarization of light in the presence of an external magnetic field. This material could then be incorporated into a photonic crystal to decrease the thickness required for the device. Before the photonic crystal could be incorporated, I had to synthesize the magneto-optical material and confirm that it had the correct properties. The magneto-optical material chosen was Bismuth and Aluminum substituted Yttrium Iron Garnet (Bi,Al:YIG), which was spin-coated onto a silicon substrate and then annealed at roughly 600 ˚C. Using an ellipsometer and an x-ray diffractometer, I measured thickness, index of refraction, absorption coefficient, and lattice spacing. A large portion of my summer was spent in optimizing the x-ray diffractometer, enabling it to provide sufficient intensities for my thin samples. Since Bi,Al:YIG is very sensitive to slight changes in temperature, spin speed, and the amount the solution is diluted, we are currently investigating these parameters carefully in order to produce high-quality thin films.

Introduction

When using lasers, it can be damaging to the equipment and data if any light from the laser is reflected back into the laser cavity. An optical isolator is an optical device that will only allow light to pass through it in one direction, making it a useful device for this problem. Optical isolators consist of three parts: an input polarizer, a Faraday rotator, and an analyzer.

Light from the laser cavity first enters the input polarizer, which polarizes it in a specific direction. It then travels through the Faraday rotator. A Faraday rotator is a device that is synthesized using ferromagnetic material, and when placed in a magnetic field, it rotates the polarization of light. The angle that the polarized light is rotated (β) is given by the following equation:

$$\beta = vBd$$

Where v is the Verdet constant, which is dependent on the material of the Faraday rotator and the wavelength of the light, B is the strength of the magnetic field, and d is the length of the Faraday rotator. The Faraday rotator should be synthesized so that the angle the polarized light rotates is 45 degrees. The analyzer is also polarized at 45 degrees with respect to the input polarizer such that all of the light from the laser can pass through it. Therefore, if any light reenters the optical isolator, it is able to pass easily through the analyzer. As the light reenters the Faraday rotator, the polarization of the light rotates an additional 45 degrees. Thus, making it impossible for any light to pass through the input polarizer because the polarization of the light is perpendicular to the input polarizer.

Currently, there are Faraday rotators that can be used in optical isolators, but they have several deficiencies. The largest of these is the length of the Faraday rotator, d, that is required to rotate the polarization of the light 45 degrees. Requiring a thick Faraday rotator not only causes the devices to be very expensive, but can also cause self-focusing and other unwanted thermal related effects.

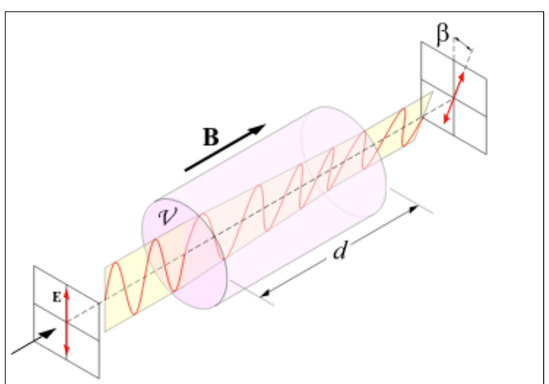

Figure 1. Faraday Rotator (wikipedia.org/wiki/Faraday_rotator)

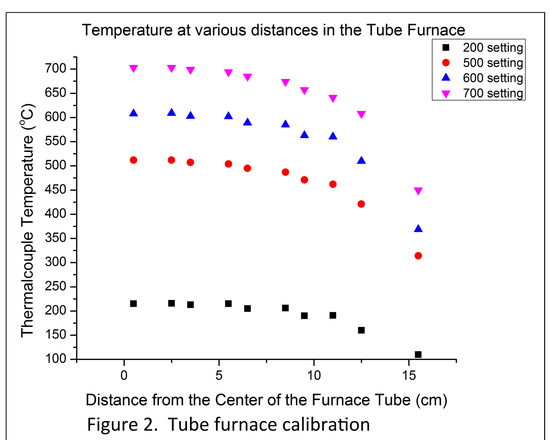

Figure 2. Tube furnace calibration

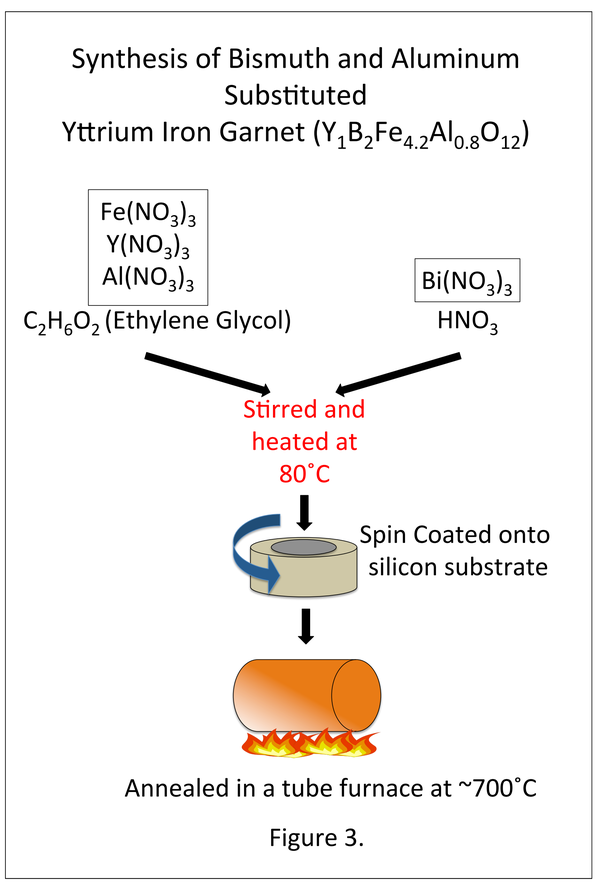

Figure 3.

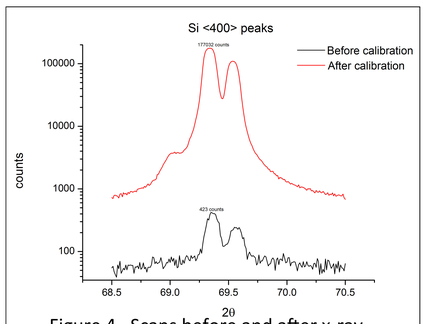

Figure 4. Scans before and after x-ray diffractometer calibration

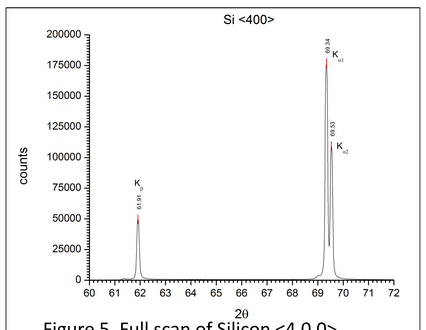

Figure 5. Full scan of Silicon <4,0,0> peaks after calibration

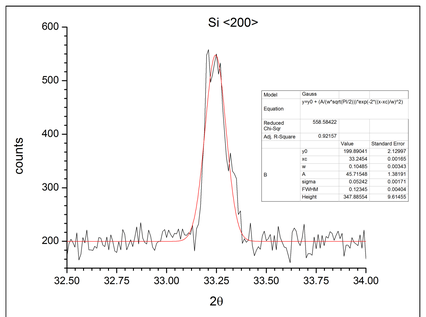

Figure 6. Plain Silicon Substrate peak

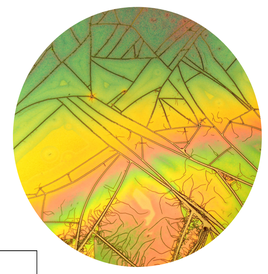

Figure 7. Sample viewed through microscope at 20X

Experimental Details

Bismuth nitrate was dissolved in nitric acid at 50˚C for 30 minutes. The solution was then added to yttrium nitrate, iron nitrate, aluminum nitrate, and ethylene glycol. The quantity of each nitrate used followed the molar ratio $Y_1B_2Fe_{4.2}Al_{0.8}O_{12}$ [1]. This solution was stirred at 80˚C for 10 minutes. After seven days the Bi,Al:YIG darkened and was applied to a silicon substrate via a spin coater. This method was chosen because it applies an extremely thin layer of Bi,Al:YIG with uniform thickness onto the silicon substrate. The samples were annealed at 650˚C for four hours to obtain crystallized Bi,Al:YIG.

Results

X-ray diffraction: Before the x-ray diffractometer could be used to measure the lattice constant of my samples, Professor Klopcic and I had to calibrate the diffractometer. This required us to replace the xenon detector, realign the soller slits, and change the height of one of the base screws. By changing the height of the base screw, it ensured that the maximum amount of x-rays could enter the detector after reflecting off the sample. I discovered that a slight change in the base screw made an enormous difference in intensity, which can be seen in Figure 4. When I scanned my samples I found various peaks, but the most peculiar ones were found at 29.9 and 33.3 degrees. Multiple papers have shown that YIG has peaks at ~33 degrees, so this was reassuring [2][3]. However, the Bi,Al:YIG was spun onto a silicon <1,0,0> substrate which also has K-alpha and K-beta peaks at 29 and 33 degrees. The peaks we saw from plain silicon substrates were consistently less intense then those with Bi,Al:YIG on them (see Figure 6). Figures 8 and 9 show scans of two samples that both have peaks at the same angles. However, 130603F had two peaks with similar intensities. This made Professor Peiris and I believe that these peaks were not solely from the substrate because K-beta decay is less probable than K-alpha.

Microscopy: Inspection of the samples under a microscope at 10X,20X,50X, and 100X showed breaks in the crystalline structure of the Bi,Al:YIG. This is from either impurities in the solution or rapid expansion during the annealing process. This effects the orientation of the samples, which weakens the intensity of the x-ray diffraction peaks. Breaks in the crystalline structure can be seen in Figure 7.

Ellipsometry: The thickness, index of refraction, and psi and delta optical constants were measured with an ellipsometer and a modeling program. The thickness of the samples were in the range of hundreds of nanometers, but the samples did not have uniform thickness which makes this measurement more difficult. The results of one sample are shown in Figures 10 and 11.

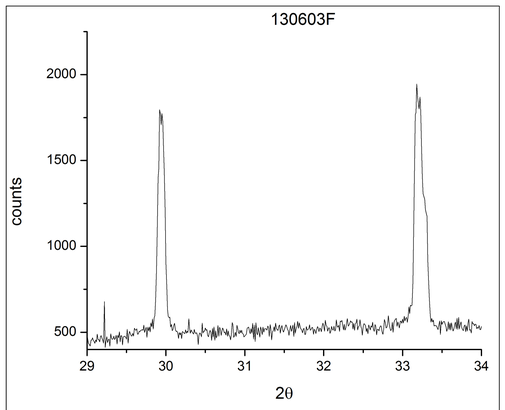

Figure 8.

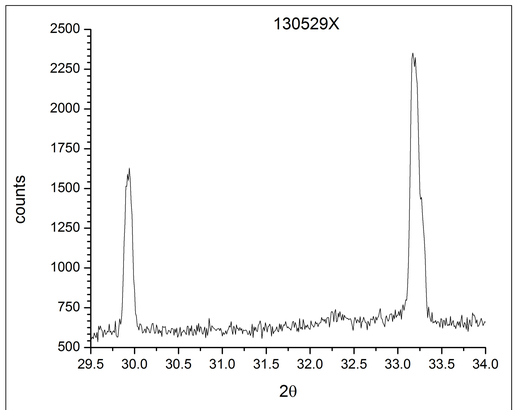

Figure 9.

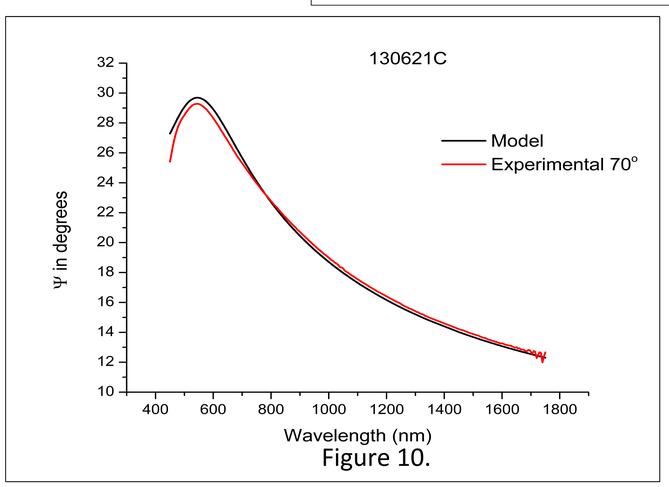

Figure 10.

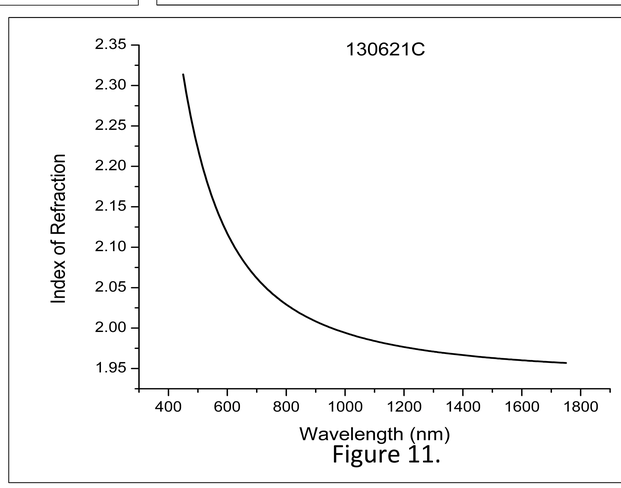

Figure 11.

References

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[2] M. Erol, Y. Ozturk, I. Avgin and E. Celik. Journal of Physics: Conference Series 153 (2009)

[3] Noorhana Yahya and Goh Kah Hean. American Journal of Applied Sciences 4 (2): 80-84, 2007